FACTORIAL DESIGN STUDY OF MINIATURE FUEL CELLS WITH MICROMACHINED SILICON FLOW STRUCTURES

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Silicon micromachining and related thin-film processing have been investigated by several research groups as an attractive candidate for the fabrication of miniature fuel cells.[1,2] Microfabrication approaches are motivated not only by the ever-expanding demand for portable electronics, but also by potential benefits in design flexibility, manufacturability, and complex device integration.[3]

Figure 1 shows an example of sixteen individual cells arrayed on a 100 mm silicon wafer, with four sets of 4-cell assemblies, connected in series with integrated gas routing and electrical contacts. Our early experimental results, however, indicated that fuel cells with micromachined flow structures do not yet perform as well as state-of-the-art configurations using graphite flow plates. Specifically, initial results using cells with micro-etched flow channels and thin-film electrical contacts typically showed lower performance than similar measurements using machined graphite. For example, 5 cm² cells using dry hydrogen and oxygen at 100 kPa yielded about 100 mW/cm² with conventional graphite, whereas the microfabricated flow structures produced only 47 mW/cm² under like conditions.

A microfabrication approach clearly introduces fundamental changes in terms of geometric parameters such as channel size, as well as material properties such as electrical conductivity. The degree to which each factor affects performance, however, is not quantitatively obvious. The fact that the performance is dependent on physical phenomena from mixed domains (fluid mechanics, kinetics, electrical resistance) has motivated an experimental design approach[4,5], rather than a first-principles model. Experimental design and factorial experiments have proven highly informative for studies in both design optimization and new-process development. The factor effects calculated from experimental data show the relative influence of each factor, and also offer insight regarding factor interactions.

The central goal of this factorial design study is to quantitatively understand the positive and negative trade-offs encountered by miniaturization of fuel cells, particularly with respect to the flow structures. Parameters under investigation in the present study include channel depth, channel width, conductive film thickness, reactant gas pressure, and cell temperature. This paper presents the experimental results and discusses the implications for fuel cell performance. Practical expectations in terms of volumetric power density for miniature cells are thus revealed.

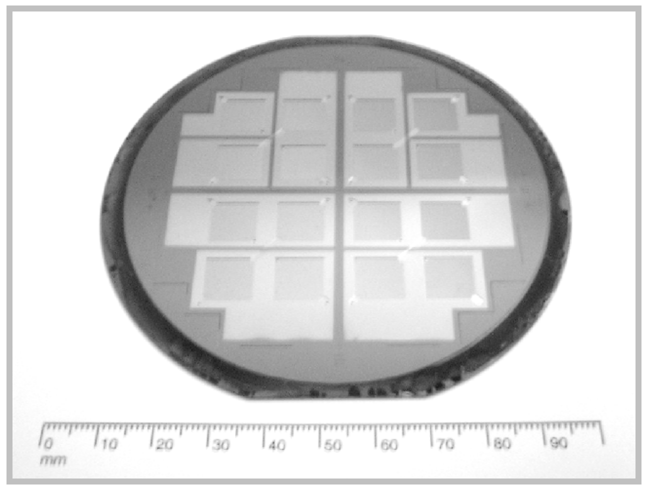

Figure 1. Micromachined fuel cell flow structures arrayed on a 100 mm silicon wafer. Sixteen unit cells are grouped in sets of four, with integrated flow passages and electrical interconnection. Feautures are defined by photolithography, channels are made by deep reactive ion etching, and metal interconnects are patterned by vapor deposition. Oxide or nitride layers are incorporated as needed for electrical isolation.

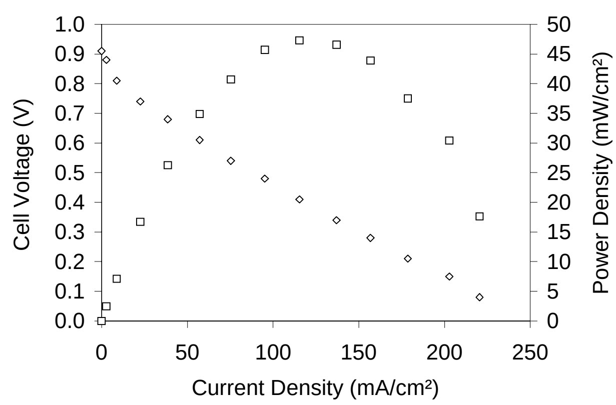

Figure 2. Example of fuel cell performance measurements using micro-patterned glass flow structures with etched channels 100 µm deep and gold conductive layers 0.5 µm thick. The membrane-electrode assembly was a 5 cm² commercial Nafion product with 1.0 mg/cm², 20 wt% Pt/C (Electrochem). Reactants were dry hydrogen and oxygen gases at 100 kPa. The cell body was run at 70 ºC, but the supply gases were not pre-heated.

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